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PROGRESS REPORT

DEVELOPMENT OF LOW TEMPERATURE DIELECTRIC COATINGS FOR ELECTRICAL CONDUCTORS

BY

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GENERAL ELECTRIC

Fourth Quarterly Report
July 16, 1962

Development of Low Temperature Dielectric Coatings for Electrical Conductors

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Fourth Quarterly Report
July 16, 1962

DEVELOPMENT OF LOW TEMPERATURE DIELECTRIC COATINGS FOR ELECTRICAL CONDUCTORS

INTRODUCTION

This report is written as a quarterly rather than a final report, since the subject contract has been extended to June 1963. However, the first phase of the program is essentially concluded, so the work to date has been summarized principally on 9 wire insulations listed below:

ML (an aromatic polyimide) enamel (Dupont enamel, G.E. coated)
ML plus aluminum phosphate treated, felted asbestos (G.E.)

Aluminum phosphate treated, felted asbestos (G.E.)
Polyvinylformal enamel (G.E. Formex)
Polyester enamel (G.E. Alkanex)
Polyvinyl chloride (Surprenant)
Polyvinyl chloride plus nylon jacket (Surprenant)
Film coated nylon (G.E.)
Fused nylon thread coating (Bridgeport Ins. Wire)
Suspensoid coated polytetrafluorothylene (Dupont Teflon-Surprenant wire)

Samples of the first two wires have been submitted to NASA, Huntsville, Alabama in response to contract requirements. The felted asbestos is designed as a radiation resistant coating but tests for resistance to radiation have not been made in accordance with the contract specifications. The remaining seven wires have been included in the evaluation for comparison and information since several of these wires were said to possess superior characteristics at cryogenic temperatures.

Samples of solid copper conductor #22 wire have been evaluated. The contract requirements are stated below:

Insulation Resistance	- 10^8 ohm - cm
Dielectric Constant	- 8 Max (10^2 - 10^6 cps)
Power Factor (Dissipation Factor)	- 0.1% (10^2 - 10^6 cps)
Dielectric Strength	- 50 volts/mil (60 or 400 cps)

Vibration - 400 cps, amplitude $\pm$ 0.25 inch

Three test conditions were included:

Room Temperature
Liquid Nitrogen Temperature ($77^{o}K$)
Liquid Helium Temperature ($4^{o}K$)
Low pressure of 1×10^{-6} Torr

These contract requirements have been modified and extended somewhat by agreement with the NASA Technical Representative as the work progressed. Such modification has been described in previous reports and is mentioned in this report also.

CONCLUSIONS

Wire Development

The polyimide, Dupont ML coated wire, as supplied to NASA, is believed to meet all of the electrical requirements under the test conditions specified except that the power factor at room temperature is in excess of 0.1%. (The vacuum conditions obtained ranged between 1×10^{-5} and 5×10^{-6} Torr instead of the 1×10^{-6} Torr specified). It should be pointed out that a power factor value of 0.1% is quite low - much lower than for the PVC now extensively used and is met only by materials such as Teflon and polyethylene. The ML coating is far more flexible at cryogenic temperatures than any other organic coating yet measured.

The ML coated wire plus aluminum phosphate, felted asbestos over-coating, as supplied to NASA, is intended to provide an inorganic insulation with expected resistance to atomic radiation and to detonation under impact in LOX (liquid Oxygen). The ML coating is incorporated to provide better resistance to moisture and higher breakdown strength than is possible with the asbestos coating alone. The power factor and perhaps the dielectric constant are higher than the values specified when measured at room temperature. However, the resistance specification is exceeded and all of the electrical properties are excellent at cryogenic temperatures. The composite coating is also quite flexible at cryogenic temperatures but less flexible than most organic coatings at room temperature. Impregnated glass fiber coatings may provide somewhat better flexibility and considerably better resistance to moisture at room temperature than asbestos. Glass fiber should have adequate properties at cryogenic temperatures also. The impregnant, however, will be subject to deterioration under atomic radiation and might be susceptible to impact in LOX.

Properties at Cryogenic Temperatures

Decreased flexibility apparently constitutes the greatest liability of wire insulation at cryogenic temperatures. Considerable difference exists between different materials thus making comparative studies important. It should be recognized that unless wire insulation is flexed while it is cold, no damage is done. Every insulated wire evaluated could be bent about its own diameter at room temperature and then immersed in liquid

helium without damage. It is probable that PVC has been used successfully in some cryogenic applications only because it was not appreciably disturbed while cold. Teflon, however, possesses superior mechanical characteristics for cryogenic use and is exceeded in this respect only by the ML coatings.

The electric strength of most wire insulations is not significantly changed at cryogenic temperatures in the absence of mechanical damage. (A slight improvement is noted for Formex and Teflon). The improvement in dielectric strength (in some cases) resulting from immersion in liquid nitrogen (and probably liquid hydrogen) can undoubtedly be capitolized on in application. At the same time the relatively poor breakdown characteristics of helium should be recognized and designed around where service problems might result. The work on the breakdown of cryogenic liquids and gases is considered to be of both scientific and engineering interest. Additional work in this area should be encouraged.

Breakdown values of wires in vacuum are generally not as high as those obtained with immersion in liquid nitrogen. Slight changes in vacuum did not seem to have appreciable influence. It is expected instead that breakdown in vacuum is limited by electrode effects as Frisco has shown in work at Johns Hopkins University.

The D.C. resistance and the A.C. loss characteristics of all insulations seem to be markedly improved at liquid nitrogen temperature and tremendously improved at liquid helium temperature. It would seem possible to make use of such properties in critical electrical applications. From the functional point of view, it seems unlikely that electrical problems will be encountered at low temperatures unless perhaps they also exist at room temperature.

Since the low electrical losses at cryogenic temperatures do not result in higher breakdown voltage, it must be postulated that breakdown failure is of the mechanical fault or intrinsic rather than thermal type. The small increase in breakdown for Teflon may be due to the characteristic increase in intrinsic strength as shown by Oakes* for linear polymers.

It is likely that heat aging may change the performance characteristics of some insulations subsequently exposed at cryogenic temperatures. For this reason the aging work proposed for the contract extension is considered to be of particular importance.

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*"The Intrinsic Electric Strength of Polythene and Its Variation with Temperature", WAG. Oakes, Tr. of IEE, 1948, Vol. 95, Pt. I, p36

PROGRAM FOR JULY AND THE FIFTH QUARTER

July Program

The July program will include:

1. Breakdown of twisted pair wire samples in liquid hydrogen.
2. Breakdown of liquid helium at temperature below the boiling point.
3. Attempts will be made to measure the electric strength of helium gas at the boiling point but problems of glow discharge are expected.
4. Dissipation factor and capacitance as a function of test frequency.
5. Preparation for thermal and vacuum aging of wire samples will be started.

Quarterly Program - July through September 1962

The program for July above will be continued and extended to include a more thorough study of the breakdown of liquid nitrogen as well.

Procurement of ribbon type conductors will be initiated looking to the development of conductors of this type for cryogenic applications. (Samples of such wire as now used in NASA operations would be appreciated). Improvement in ML wire coating with different manufacturing techniques will be sought in an effort to overcome the areas of low electric strength now encountered.

DESCRIPTION OF WIRE COATINGS DEVELOPED FOR CRYOGENIC APPLICATIONS

The polyimide (Dupont ML) coatings were commercial magnet wire production except that the samples finally supplied (G.E. wire section - Schenectady) were subjected to three rather than one factory bakes. The problem of adequate bake with ML coating had been originally discovered with flexibility measurements at liquid helium temperatures on three samples of different bakes supplied through the courtesy of the G.E. Fort Wayne Laboratories Operation (see 3rd quarterly report - April 15, 1962). The original ML coating supplied by the G.E. Wire section in Schenectady for the earliest work had adequate flexibility. The subsequent sample, as first supplied, was brittle but became flexible (at cryogenic temperatures) after two subsequent factory bakes. It is believed that suitably flexible wires can be obtained in one normal factory operation by modification of techniques including an increase in tower temperature.

The ML coating, as finally produced, had an insulation thickness of .0012 in. with a smooth, dark brown finish. The color was not completely uniform varying to some extent from length to length and from one side to the other in some places. The non-uniformity may have arisen from the repeated bakes and associated handling. Points of voltage weakness (at about 400 volts) were noticed when lengths of the wire were tested in salt water. The wires with the asbestos overcoating (see below) seemed to have more dielectric weak points than the uncoated ML enamel but the difference may have been due simply to sample variation.

The process for making the aluminum phosphate treated, felted asbestos wire has been described in the first quarterly report - September 13, 1961. The asbestos felting technique is exactly the same as that used commercially by the G.E. Wire and Cable Dept. at Lowell, Mass. For the subject wire, a 96% non-ferrous asbestos lap was used and impregnated with aluminum phosphate solution supplied by R. Girard of the General Engineering Laboratory, General Electric Co., Schenectady, as follows:

244 grams.	Aluminum hydrate - $Al(OH)_3$ Calcined 3 hrs. at 1550°F
318 grams.	85% Orthophosphoric acid - H_3PO_4
424 grams.	Water

The above was heated 2½ hrs at 90 - 100C with slow but constant stirring.

The resulting suspensoid was applied to both the ML coated wire and to the felted coating before it was run through the final sizing die. It was not necessary to use any thinner as described in the first report. The wire was baked just enough to prevent blocking. An extremely tough, smooth white coating was obtained which varied in thickness from .0045 to .0060 inches in the areas measured. A thicker coating was not attempted since the results with the earlier samples indicated the superiority of the thinner coating.

OBSERVATIONS AND SUMMARY OF TEST RESULTS

Electrical Properties

D.C. Resistance and AC Properties

The accurate measurement of specific resistance and the AC characteristic so far has failed because an adequate electrode system has not been designed. All of the electrodes applied directly to the wire have given evidence of separation or spalling when exposed at cryogenic temperatures. Even various types of electrodes overcoated with resinous coatings give evidence of separation. In consequence measurements have been made on bundled conductors as described below.

A variety of bundled, twisted and mandrel-wrapped samples have been investigated. The maintenance of a constant value of capacitance at room temperature after cycling to cryogenic temperatures was used as the criterion of a successful sample. The sample shown in Fig. 1 and Photo 1 gave by far the best performance in this respect. The sample consists of 6 wires placed concentrically around an inner wire with a very slight twist. The wires are held together under considerable positive pressure by the action of heat shrinkable Teflon tubing placed in bands about the sample as shown. The ends of the 6 outer wires are flared away from the central wire as illustrated. Measurements are made between the central conductor and the 6 outer conductors connected in parallel. Samples have been measured without guarding. It is possible to electrically guard the sample to prevent leakage but sample preparation is tedious and probably unnecessary except perhaps for the asbestos insulated samples.

The results of the electrical measurements are given in Table I - IV. The relatively small changes in capacitance except for the asbestos insulated wires are noteworthy and have been calculated as ratios in Table V. It should be realized that liquid nitrogen (dielectric constant = 1.43) will increase the capacitance as compared to air but that liquid helium (dielectric constant = 1.048) will have relatively little effect in this respect. Hence it is possible to compare the values in air with those in liquid helium without considering the effect of the liquid on the value of capacitance.

The very small increase in capacitance for Teflon in liquid helium confirms the small change that would be expected for such a non-polar material resulting only from small changes in density or dimension. The contrasting large decrease in capacitance for polyvinyl chloride (PVC) and for the moisture containing asbestos is also to be expected for such polar materials. At cryogenic temperatures the dipole action is essentially frozen so that these materials have low dielectric constants. When soaked in water, the asbestos sample has such a high conductivity that it cannot be measured. Yet at cryogenic temperatures, the capacitance of the water soaked asbestos (see Table IV) is quite low. The values in liquid N_2 and in liquid He are quite similar in this case, probably because water impregnates both samples and the influence of the liquid N_2 is thereby minimized.

Table II illustrates the startling effect of cryogenic temperatures in lowering the dissipation factor of all the wire samples. The impregnation of the samples with liquid nitrogen or helium should not affect the dissipation factor since the losses of the liquids themselves were found in separate work to be very low. In liquid helium the losses for all the wire insulations are so low that the dissipation factor measurement becomes marginal or impossible in some cases. As would be expected, ionic migration and dipole losses are "frozen" out at liquid helium temperatures.

Similarly the values of resistance reach such high values in cryogenic fluids, as shown in Table III, that they become difficult to measure. In liquid helium the measured values of resistance are so high that the measurement accuracy is affected by noise and circuit leakage. The values in some cases lie beyond the sensitivity of available instruments. In fact in liquid helium the resistance values are so high that no true comparison can be made between samples.

It is regreted that accurate measurements of specific electrical properties have not yet proved to be feasible. Such values would be of considerable theoretical interest. However, the measurements made are actually much closer to the practical situations involved in use.

Electric Breakdown

It has proven relatively easy to make breakdown measurements of NEMA twisted pair wire samples in liquid nitrogen. In liquid helium some trouble has been encountered with glow discharge and breakdown between test leads in liquid and particularly in gaseous helium above the immersed test samples. Improvements in test fixtures (see later section) have largely overcome the experimental problems. Problems in making measurement in vacuum at cryogenic temperatures have involved several attempts with the ultimate development of a relatively satisfactory method (see test methods section). Measurements now have been made with vacuums ranging from 10^{-5} to 5×10^{-6} Torr. The electric breakdown measurements are summarized in Table VI. A few additional measurements made in vacuum at liquid nitrogen temperature (77K) are given in Table VII. These measurements were made largely to substantiate the supposition that little difference would be found between measurements at 77 and 4 K in vacuum.

Analysis of the results in Table VI leads to interesting observations. The electric strength of the medium surrounding the twisted pair wire sample contributes in an important way to the breakdown value for the wires. For this reason the program was extended with the approval of the Technical Officer at NASA to include a study of breakdown in cryogenic liquids and in gases at cryogenic temperatures. As will be amplified later, liquid helium was found to have very poor electrical breakdown characteristics - not much better than air at room temperature. On the other hand liquid nitrogen does contribute to increased breakdown much as immersion in oil would particularly with "spacing" insulation like asbestos and glass fiber. Vacuum at liquid helium temperature (4K) significantly increases the breakdown voltage of the "spacer" type insulations just as liquid nitrogen does but generally not to quite the same degree.

Except for the influence of the surrounding medium, there is no evidence from the data in Table VI that low temperature itself has a significant effect on breakdown voltage of the wire insulations studied. (Relatively small changes are noted in some cases.)

Breakdown of Cryogenic Liquids and Gases

Measurements have been made of the breakdown voltage between ½" steel balls in liquid nitrogen, hydrogen and helium. Measurements have been made in hydrogen gas just above the liquid level and presumably at close to the boiling point of 20°K. (Other cryogenic gases will be evaluated later.) Special fixtures have been developed for the purpose as described in the section on test methods.

Fig. 2 gives the voltage breakdown between ½" steel balls in liquid nitrogen, helium and hydrogen (with gaseous hydrogen for comparison). The individual values for nitrogen and helium are given in the Third Quarterly Report - April 15, 1962 (Fig. 2). A great many breakdown measurements were made in liquid hydrogen because of the variability found. The results have been plotted on arithmetic (Gaussian) probability paper. The probable average (PA), the 90% value and the 10% value (as well as the arithmetic average) are given in Table VIII. Review of the data indicates that the values for liquid hydrogen at 20K and spacings of 7 and 8 mils are questionable. Consequently these points are connected by a dotted line in Fig. 2.

The results for liquid hydrogen at low temperatures are plotted in Fig. 3 in order to illustrate the large spread of the test results. It was postulated that gaseous hydrogen dispersed in liquid H_2 at the boiling point might be responsible for the wide variation although no bubbles of gas could be seen visually in the body of the liquid. A vacuum was pulled on the hydrogen, cooling it until a considerable quantity of solid hydrogen collected at the top of the liquid. Atmospheric pressure was then restored so that tests could be made in the liquid at the temperature of melting hydrogen - 14°K. The variability of these results is at least as great as those at 20°K. It is possible that finely dispersed particles of solid air contaminate the liquid hydrogen. Such particles, with their relatively high dielectric constant as compared to liquid hydrogen, may be responsible for the variable results in the breakdown tests on liquid hydrogen and helium.

The voltage breakdown of gases has been studied for at least 100 years but to the authors knowledge no measurements have been made on the common gases-nitrogen, hydrogen or helium, at or close to their boiling temperatures. Such breakdown values as a function of spacing are given in Fig. 4 for hydrogen. These results are remarkable in that a very exact linear relationship is obtained with very little variability in test results. The curves at the bottom of figure 4 are taken from the literature* for hydrogen

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* W.R. Carr, Phil Trans. of Royal Soc. A 201, 403 - 1903
F. Paschen, Wiedemanns Annalen 37, 69 - 1889
A. Orgler, Annelen der Physik (4) 1, 159 - 1900

and air at room temperature. Since the literature gives peak values, they have been divided by 1.4 to give results comparable to the AC (RMS) values. Individual test results for two series of measurements in air at 23°C have been included also. The values of the second series are obviously too high perhaps because the voltage was raised too rapidly.

Since the breakdown voltage of a gas is related to its density, attempts have been made to calculate the breakdown of hydrogen at 20°K from the room temperature values as shown in Fig. 5. Two methods of calculation were used. In one, the values of breakdown for each spacing at 20°C were multiplied by the ratio of the gas densities -

$$\frac{H_2 \text{ at } 20K = 0.055}{H_2 \text{ at } 293K = .00515} = 10.65$$

to give the upper dotted curve in Fig. 5. For the other approach the spacing was multiplied by the same ratio and the breakdown value taken from the literature and plotted to give the lower dotted curve. It is apparent that density may well be an important contributing factor. Nevertheless, the superior electric breakdown of hydrogen is obvious when it is recognized that gaseous hydrogen at 20°K is less dense (0.05 lb/ft^3) than air at 23°C (.074 lb/ft^3) but its breakdown voltage is much greater. In fact gaseous hydrogen at 20 K has a higher breakdown voltage than liquid helium at 4.2 K. The superior properties may well be due to gaseous hydrogen's electronegative character which is known to contribute to electron capture. It is more difficult to explain the high breakdown voltage of liquid hydrogen and the low values for liquid helium.

Mechanical Properties

Although vibration tests were specified in the original contract, it became apparent that such tests were difficult to control and interpret for wire coatings even at room temperature. In consequence with the approval of the NASA Technical Officer, repeated flexure around mandrels was substituted. The mandrel tests made in liquid nitrogen and helium proved to be repeatable and significant. In fact it is apparent that mechanical embrittlement is the principal limitation to the use of many wire insulations at cryogenic temperatures.

Inorganic insulation, like the aluminum phosphate treated asbestos, is somewhat brittle at room temperature but its characteristics in this respect do not seem to change even at liquid helium temperature. On flexing, such a felted coating tends to tear and the fibers separate. Even with such deterioration, spacing and considerable voltage capability is retained unless conducting contaminant works into the cracks and discontinuities.

Organic wire insulations are all subject to embrittlement at cryogenic temperatures but there seems to be little if any difference between the effect of liquid nitrogen (77K) and liquid helium (4K). Many results with the repeated mandrel flexibility tests were summarized in the third quarterly report and these results with additional data obtained in the last quarter are summarized in Table IX. It should be recognized that this

table reports the first evidence of mechanical damage such as fine crazing. In many applications such damage would not be of functional significance. However, at somewhat smaller mandrel diameters than those shown in Table IX, severe mechanical damage is obtained. The absence of all cracking with adequately baked ML enamel even over a 1/8 in. mandrel is of significant functional value. All of the other organic wire enamels are badly split, peeled, chipped or spalled when bent over a 1/8 in. mandrel at cryogenic temperatures. Commonly used PVC coatings are badly damaged on a 1½ in. mandrel and a nylon jacket on a 1 3/4 in. mandrel. Pictures of various types of failure are given in the third quarterly report but are not repeated here. It is apparent from visual observation that mechanical damage in bending at cryogenic temperatures arises from the lack of elongation in the resin coating, lack of adhesion to the base copper and perhaps delamination between layers of coating.

TEST METHODS AND FACILITIES

Electric Breakdown

Measurement techniques for all electrical properties have followed ASTM - in this case, D-149. Two transformers have been used rated at a maximum voltage of 15 and 30 KV. A variable auto-transformer (General Radio Variac) has been used to vary the primary voltage. The secondary voltage of the 15 KV transformer was measured directly using an electronic voltmeter with two voltage scales across one leg of a capacitance divider. The voltage of the 30 KV transformer was measured with a tertiary winding using an accurate, calibrated laboratory type, iron-vane voltmeter. The breakdown current was interrupted by a fast operating relay in the primary circuit within 1 to 3 cycles after failure to avoid introducing excess heat or burning of the electrodes or samples.

After initial consideration, the NEMA twisted pair sample was selected for breakdown measurements on wire. This simple sample is well accepted in the industry and has the advantage of applying a positive pressure between the wires which appears to be maintained at cryogenic temperatures. The NEMA sample is disadvantageous in that only a relatively few areas are in contact so that it does not search out discontinuities or points of low voltage breakdown. Mandrel breakdown samples were considered but positive contact between wires could not be assured at cryogenic temperatures. The concentric bundled sample ultimately developed for capacitance and dissipation factor tests (described below) might be used as a breakdown sample supplying more contact area.

For breakdown measurements of cryogenic liquids and gases themselves, one-half inch diameter steel ball electrodes were selected. A great deal of the extensive work described in the literature has used spherical electrodes* of this type and they or spheres of somewhat different diameter are standard or fast becoming standard the world over. Unfortunately, in the United States specifications for breakdown in liquids have bogged down in the traditional use of square edged, cylindrical electrodes and

* Some of the work involves electrodes with special curvature to give uniform stress - Rogowski electrodes.

change here is difficult and slow. In this work the accurate adjustment and measurement of the spacing between spheres mounted at the bottom of a cryostat proved to be a problem. The top sphere was held by a magnet** against the bottom end of a long thin stainless steel tube as shown schematically in Fig. 6. The spacing was adjusted by a micrometer mounted at the top of the device.

Such specialized inserts for the cryostats posed special problems in test on wires and fluids with both hydrogen and helium. With helium breakdown was obtained between uninsulated lead wires and terminals in the gas phase over surprisingly long distances. It was finally found necessary to keep every uninsulated portion of the assembly under the test liquid and to bring Teflon insulated lead wires through potted holes in the top without opening the lead insulation. For tests in hydrogen, it was obviously very important to provide means for complete purging and to avoid the possibility of air diffusing back into the device.

In the course of the program, several types of approaches have been taken to the design of fixtures for cryogenic tests and they have been described in previous quarterly reports. Here, only the presently used fixtures are described since they have been designed to be adequate for use in both hydrogen and helium. Though designed for tests in liquids, it is also possible to make tests in the gas by lowering the boiling liquid level below the sample. The relatively simple fixture for sphere gap tests is shown schematically in Fig. 6. This structure must be made quite rigid to prevent misalignment of the test spheres. Use of materials with low thermal expansion like Invar help in making a structure which comes to dimensional equilibrium as quickly as possible. In use, the micrometer is adjusted so that the balls just touch as determined by electrical contact. The micrometer is then backed off the desired amount. After test the micrometer is returned to the contact position to determine the accuracy and stability of the spacing measured. For wire tests, the fixture shown schematically in Fig. 7 has been designed. It is usually possible to test 12 samples arranged concentrically but fewer samples may be used if necessary to avoid flashover between them.

The test fixture for the breakdown of wires in vacuum at cryogenic temperatures proved to be more difficult than originally suspected. It is necessary to provide large passageway for the removal of gas and yet to provide intimate contact with close spacing for adequate thermal transfer to the sample - two incompatable objectives! (It must be remembered that in vacuum at cryogenic temperatures heat flow must occur by conduction since convection and radiation are ineffective.)

An effective solution has been found by containing the cryogenic fluid on the inside and underneath the sample as shown schematically in Fig. 8. (This ingenious idea was suggested by Lloyd Nesbitt). Both wires of the test sample are thereby connected to the cryogenic heat

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** A scheme developed by J.F. Dexter, Dow Corning Corp., Midland, Mich.

sink - one is soldered directly to the central filling tube and the other to a sapphire post insulator which provides good thermal contact to the container holding the cryogenic liquid. Since this fixture is more complicated than the others, an engineering drawing, (Fig. 9) is included. (42ID441)

DC Resistance, Capacitance and Dissipation Factor

Again ASTM methods were followed - D-150 and D-257 - for the DC and AC loss measurements.

The following instruments were used:

DC	-	Keithly 200 B electrometer, 2008 shunt, 2004A supply
60 cps	-	G.E. high Voltage Schering Bridge (150 volts)
1 Kc and 10Kc	-	Wayne Kerr Model B221 Universal Bridge
100 Kc and 1 Mc	-	Wayne Kerr Model B601 RF Bridge

All of the instruments are capable of making guarded (three terminal) measurements which is particularly important since the effect of long leads to the samples in the bottom of the cryostats must be eliminated.

The development of a suitable sample - electrode combination for measurement at cryogenic temperatures has proven to be a formidable problem as reported in previous quarterly reports. The problem involves separation of the electrode from the wire insulation surface during exposure at cryogenic temperatures. Such electrode induced errors are often difficult to detect and separate from other effects but can introduce large deviation in measurement. The method of determining the source of such errors is subtle but involves measurements at different frequencies and experience as to the appropriate trends in results.

Since no suitable electrode was developed which could be applied directly to the wire surface, it was decided to make measurements between the wires themselves. It then becomes imperative to establish uniform and positive contact between two or more insulated wire surfaces for a sufficient distance to make measurement possible and to maintain such contact through cycles to cryogenic temperatures. The area of contact between the wires in the NEMA twisted pair dielectric test specimen is not adequate for either DC or AC loss measurements. Mandrel wrapped specimens have sufficient area of contact but fail to maintain positive and uniform contact through temperature cycles. Fortunately E. McGowan and J. Atkins were able to devise a bundled speciman consisting of 6 wires grouped concentrically around a central wire which could be held together with positive and uniform contact by bands of shrinkable Teflon tubing as shown in Fig. 1 and Photo 1. The 6 outer wires are given a slight twist to help hold the structure together. Measurement is made between the central wire and the 6 outer wires connected in parallel with the ends bent back as shown in the figure to give leakage distance. It appears possible to guard such samples against end leakage by applying silver paint or fine wire guard electrodes at each end of the central conductor since variation in the

area of the guard electrode is not important. Such guarding is tedious and except possibly for the asbestos samples at room temperature does not appear to be necessary.

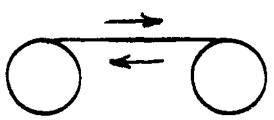
It must be realized that AC measurements on the concentric, bundled samples will include measurement also of the space between the conductors not occupied by wire insulation. If air or a low loss fluid occupies this space, the values of capacitance and dissipation factor measured will be somewhat lower than the true specific value for the insulation itself. Fortunately the dielectric constants of liquid helium and air are so similar that for this case comparison of results is valid. The introduction of a material like liquid nitrogen into the space between the wires will increase the capacitance somewhat but have only a small effect on the dissipation factor.

Fortunately the above discussion is largely academic because the values measured with the concentric, bundled sample are probably more meaningful for practical application than the specific values would be. In use wires are apt to run in bundled configuration much like that of the test sample.

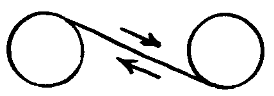
As with the breakdown test, the fixtures for cryogenic test are also important. Fortunately for DC and AC loss measurements only low voltages are used. Consequently the test fixtures used for the breakdown work are adequate except that shielded leads must be used. In this case connections can be made, because tests are made at voltages below those which cause trouble from breakdown or glow discharge.

Mechanical Tests

For perhaps 25 years the author has attempted periodically to make vibration studies of wire insulation at room temperature without success. Instead it has seemed wise to separate the mechanical problem into its parts and evaluate them separately - usually flexibility and abrasion. In working with wires at cryogenic temperatures it became quickly apparent that they were susceptible to damage from flexing and probably from crushing where one wire came in contact with another under pressure. Consequently with the approval of the NASA Technical Officer, mandrel flexibility tests have been substituted for the proposed flexing tests. To adapt the mandrel test to a form convenient for use at the bottom of a cryostat, two mandrels were used and the wire run from one to the other as shown in the diagram below.



Forward Bend



Reverse Bend

As the diagrams show, it is possible to utilize either a forward or the more severe reverse bend. It was found that damage to the wire accumulated as it was wound back and forth between the two mandrels. However, after about 10 back and forth "bends", little damage occurred on subsequent flexing. To make sure that the repeated flexing had progressed completely, it has become usual practice to use a minimum of 30 repeated flexing cycles. Samples may also be examined after 1, 5, 10 and 20 repeated flexing cycles to determine the rate and degree to which damage has occurred.

For measurement the test mandrels are located at the bottom of long, thin stainless steel tubes which can be immersed in the liquid nitrogen or helium. The tubes can be turned back and forth by hand at the top in such a way that slight tension is maintained on the wire. On removal, the wire samples are examined under a low power microscope for cracks or other mechanical damage. When questions arise, the presence of open cracks in film coated wires can be detected by immersing the sample in slightly salted water and measuring resistance between the wire and the water.

TABLE I

1000 Cycle Capacitance

Wire	Spec. No.	At R.T. 23° C	In Liquid N_2 77° K	In Liquid H_e 4 K	At R.T. 23° C
HF	1	56.8	57.0	49.3	56.1
(Formex)	2	59.5	59.3	51.9	59.2
	3	64.0	62.9	55.3	64.0
	4	61.6	60.2	53.3	61.8
HYT	1	55.1	57.0	49.7	50.4
(Alkanex)	2	49.2	52.0	45.0	51.0
	3	50.6	53.7	46.4	49.9
	4	48.6	51.2	44.0	48.0
ML	1	57.7	65.4	56.7	57.4
poor balance →	2	42.2	45.8	40.6	57.1
	3	56.2	63.7	54.8	46.5
	4	60.8	65.7	58.3	62.2
Asbestos	1	78.5*	17.5	14.4	80.0*
(dry)	2	87.0*	18.0	14.7	84.5*
	3	82.9*	18.5	15.4	87.2*
	4	91.5*	18.1	14.8	82.6
Asbestos/ML	1	71.7*	26.6	22.2	75.5*
	2	55.7*	25.0	25.0	88.1
	3	75.0*	29.1	21.0	59.7
	4	73.9*	23.7	20.0	77.7
PVC	1	35.4	26.0	25.2	37.3
	2	34.2	25.4	24.5	36.3
Teflon	3	38.6	45.9	39.2	38.6
	4	43.0	51.3	44.4	44.6

*These specimens were very difficult to balance since they drifted rapidly.

TABLE II

1000 Cycle Dissipation Factor

Wire	Spec. No.	At R.T. 23° C	In Liquid N_2 77° K	In Liquid He 4° K	At R.T. 23° C
HF	1	0.0065	0.0014	0.00029	0.0064
(Formex)	2	0.0066	0.0014	0.00034	0.0066
	3	0.0072	0.0016	0.00037	0.0070
	4	0.0072	0.0017	0.00038	0.0069
HYT	1	0.0046	0.00056	0.00003	0.0044
(Alkanex)	2	0.0044	0.00058	0.00011	0.0094
	3	0.0043	0.00059	couldn't read bridge too low	0.0041
	4	0.0046	0.00065	couldn't read bridge too low	0.0043
ML	1	0.0015	0.00073	0.00006	0.0018
poor balance →	2	------	0.00056	0.00008	0.0019
	3	0.0016	0.00080	0.00014	0.0041
	4	0.0016	0.00078	0.00019	0.0019
Asbestos	1	0.62	0.0009	couldn't read bridge too low	0.40
	2	0.63	0.0011	0.00022	0.41
	3	0.54	0.0011	couldn't read bridge too low	0.39
	4	0.82	0.0018	0.00021	0.42
Asbestos/ML	1	0.19	0.0009	0.00028	0.24
	2	0.19	0.0005	0.00026	0.22
	3	0.19	0.0012	0.00015	0.22
	4	0.23	0.0012	0.00048	0.26
PVC	1	0.088	0.0015	0.00016	0.091
	2	0.086	0.0014	0.00006	0.089
Teflon	3	0.0032	0.0013	too low to read	0.011
	4	0.0035	0.0016	0.00004	0.011
	4 rpt			0.00007	

TABLE III

D-C Resistance Measurements

Applied Voltage = 500v

Wire	Spec. No.	At R.T. 23° C	In Liquid N_2 77° K	In Liquid H_e 4° K	At R.T. 23° C
HF (Formex)	1	1.0×10^{14}	2.0×10^{15}	1.0×10^{16}	2.1×10^{13}
	2	0.8×10^{14}	1.7×10^{15}	5.0×10^{16}	1.7×10^{13}
	3	1.0×10^{14}	1.8×10^{15}	0.7×10^{16}	3.8×10^{13}
	4	1.2×10^{14}	2.2×10^{15}	0.8×10^{16}	1.3×10^{13}
HYT (Alkanex)	1	4.1×10^{13}	25.0×10^{15}	5.0×10^{16}	1.0×10^{13}
	2	4.1×10^{13}	1.8×10^{15}	5.0×10^{16}	0.9×10^{13}
	3	8.0×10^{13}	1.6×10^{15}	5.0×10^{16}	1.7×10^{13}
	4	2.0×10^{13}	3.8×10^{15}	5.0×10^{16}	0.8×10^{13}
ML	1	1.3×10^{13}	1.8×10^{16}	3.0×10^{16}	3.5×10^{12}
	2	3.1×10^{13}	5.5×10^{16}	2.5×10^{16}	3.8×10^{12}
	3	1.1×10^{13}	2.2×10^{16}	0.7×10^{16}	5.0×10^{12}
	4	1.2×10^{13}	1.4×10^{16}	too high to read	3.5×10^{12}
Asbestos (dry)	1	3.3×10^{7}	2.7×10^{15}	1.7×10^{16}	5.0×10^{7}
	2	3.1×10^{7}	10.0×10^{15}	5.0×10^{16}	5.0×10^{7}
	3	2.6×10^{7}	5.0×10^{15}	1.7×10^{16}	2.2×10^{7}
	4	1.9×10^{7}	2.5×10^{15}	0.8×10^{16}	2.2×10^{7}
Asbestos/ML	1	7.1×10^{9}	2.5×10^{15}	too high to read	4.1×10^{10}
	2	8.6×10^{9}	1.7×10^{15}	2.5×10^{16}	2.5×10^{10}
	3	38.0×10^{9}	5.0×10^{15}	2.5×10^{16}	6.2×10^{10}
	4	9.0×10^{9}	3.3×10^{15}	2.5×10^{16}	2.0×10^{10}
PVC	1	2.5×10^{12}	1.0×10^{15}	no readings possible	5.0×10^{12}
	2	3.3×10^{12}	1.5×10^{15}		3.1×10^{12}
Teflon	3	2.0×10^{14}	8.3×10^{14}	no readings possible	1.2×10^{14}
	4	3.3×10^{14}	25.0×10^{14}		0.6×10^{14}

TABLE IV

Capacitance, Dissipation Factor and D-C Resistance of Wet* Asbestos at Liquid N_2 & Liquid H_e Temperature

Capacitance (pf)

Spec#	In Liquid N_2-77°K	In Liquid He -4°K
1	broken lead	24.4
2	26.8	25.2
3	27.6	25.6
4	27.0	25.2

Dissipation Factor

Spec #	In Liquid N_2-77°K	In Liquid He -4°K
1	broken lead	0.00024
2	0.00089	.00019
3	.00086	.00019
4	.00076	.00032

D-C Resistance (500 v applied)

Spec #	In Liquid N_2-77°K	In Liquid He -4°K
1	broken lead	2.5×10^{16}
2	4.1×10^{13}	2.5 "
3	5.0 "	5.0 "
4	12.5 "	0.8 "

*Immersed in water at room temperature for at least 24 hours

TABLE V

Ratio of Capacitance (Avg. Values)

Room Temperature/Immersion in Cryogenic Liquid

WIRE	Liquid N_2 77K	Liquid He 4K	Original/Final at Room Temp.
Heavy Formex	1.01	1.15	1.005
Heavy Alkanex	0.95	1.10	1.02
Heavy ML	0.90	1.03	0.97
Asbestos (dry)	4.81	5.72	1.02
ML + asbestos	2.66	3.15	0.92
PVC	1.37	1.40	0.945
Teflon	0.84	0.98	0.98

TABLE VI

Short Time Dielectric Breakdown (in Volts)
Twisted Pairs on Insulated Wires

(Tested at 60 cycles in various mediums and temperatures)

WIRE	Nominal wall Thickness	AIR (23°C) (296°K)	LIQUID NITROGEN (77°K)	LIQUID HELIUM (4°K)	VACUUM (4°K)	(Press.) Torr.
Heavy Formex	.0014"	5400	9200	8800	7400	
		5600	9200	6200	7700	
		—	8300	5900	8400	
		5500	8900	6970	7830	(4.8×10^{-6})
Heavy Alkanex	.0014"	9100	9900	6700	8200	
		8800	10600	8900	7800	
		9800	8800	9100	8500	
		9230	9770	8230	8270	(1×10^{-5})
Heavy ML (Dark bake)	.0013"	10700	9200	7200	7400	
		9800	9200	6800	7700	
		—	8800	7700	7500	
		10250	9070	7830	7530	(6×10^{-6})
Heavy ML (spool #3) (Light bake plus two rebakes)	.0010"	6100	5700	6300	5500	
		6700	6100	6300	5700	
		6200	6700	5800	6100	
		6330	6170	6130	5780	(6×10^{-6})
Heavy ML (Spool #4) (Light bake plus two rebakes)	.0010"	5600	5600	5900	5200	
		5800	6200	5500	5700	
		5900	6900	5300	5300	
		5770	6230	5570	5400	(1.4×10^{-5})
Teflon	.0015"	5900	7700	6200	6100	
		6400	8200	6400	7700	
		5900	7200	—	8400	
		6070	7700	6300	7400	(4.8×10^{-6})
Fused Nylon	.0007"	3400	3800	2600	4700	
		3400	3800	4500	4400	
		3400	4700	3100	3800	
		3400	4100	3400	4300	(1×10^{-5})
Single Nylon (Solution Coated)	.0008"	4300	4500	3000	4700	
		4000	5400	3100	4600	
		4000	5200	3700	4900	
		4100	5030	3270	4730	(1.4×10^{-5})
Asbestos (Felted)	.0050"	1000	4200	2000	3600	
		1000	3500	2000	3300	
		1000	3600	2000	3500	
		1000	3770	2000	3470	(1.2×10^{-5})

TABLE VI (Cont.)

Short Time Dielectric Breakdown (continued)

WIRE	Nominal wall Thickness	AIR ($23^{o}C$) ($296^{o}K$)	LIQUID NITROGEN ($77^{o}K$)	LIQUID HELIUM ($4^{o}K$)	VACUUM ($4^{o}K$)	(Press.) Torr.
Asbestos over ML	.0050"	5900	7600	6100	5600	
		4300	8300	5800	5400	
		4800	7700	6000	5700	
		5000	7870	5970	5570	($1.2x10^{-5}$)
Asbestos over ML plus ML coating	.0052"	5700	8800	2780	8600	
		5300	—	3370	7200	
		5500	—	3200	7200	
		5500	8800	3120	7670	($2.4x10^{-5}$)
Glass with ML Coating	.0066"	2000	11200	1380	8400	
		2000	11300	1280	7400	
		2300	—	1300	8100	
		2100	11250	1320	7970	($2.4x10^{-5}$)

TABLE VII

Short Time Dielectric Breakdown (Volts) of Twisted
Pairs of Insulated Wires Tested Under Vacuum
at Different Temperatures

WIRE	Nominal Wall Thickness	Tested Under Vacuum			
		(77^{o}K)	Pressure Torr	(4^{o}K)	Pressure Torr
Heavy Formex	.0014"	7000		7400	
		—		7700	
		—		8400	
		7000	(1.2×10^{-5})	7830	(4.8×10^{-6})
		(2500 v/mil		(2800 v/mil)	
Heavy ML (Dark bake)	.0013"	6800		7400	
		—		7700	
		—		7500	
		6800	(1.2×10^{-5})	7530	(6.2×10^{-6})
		(2620 v/mil)		(2900 v/mil)	
Teflon	.0015"	7000		6100	
		—		7700	
		—		8400	
		7000	(1.2×10^{-5})	7400	(4.8×10^{-6})
		(2340 v/mil)		(2460 v/mil)	
Fused Nylon	.0007"	5500		4700	
		—		4400	
		—		3800	
		5500	(1.2×10^{-5})	4300	(1×10^{-5})
		(3930 v/mil)		(3060 v/mil)	
Asbestos (Felted)	.0050"	3000		3600	
		—		3300	
		—		3500	
		3000	(1.2×10^{-5})	3470	(1.2×10^{-5})
		(300 v/mil)		(350 v/mil)	

TABLE VIII

Voltage Breakdown KV
in
Liquid Hydrogen
between
½" Spheres

Spacing Mils	Arith. Avg.	P.A.	10%	90%	Spacing Mils	Arith. Avg.	P.A.	10%	90%
1	2.9	3.0	1.6	4.3					
2	4.6	4.6	3.1	5.8	2	7.1	7.0	6.0	8.0
3	6.9	6.7	4.0	9.4					
					4*	10.9	10.6	6.5	14.7
5	10.5	10.0	7.7	12.4					
					6	13.1	12.9	9.0	16.8
7	14.7	14.7	12.5	16.9					
8*	16.8	17.2	12.7	21.2	8	14.7	14.8	10.4	19.0
					10*	16.9	16.6	12.3	20.9

*Data are insufficient or too scattered to give reliable values

TABLE IX

Repeated Mandrel Flexibility Tests

Comparison of Wire Insulations in Liquid Nitrogen and Helium

WIRE	Mandrel Diameter (in.) on Which First Failure Occurs: Forward Bond, Liquid N_2	Forward Bond, Liquid He	Reverse Bond, Liquid N_2	Reverse Bond, Liquid He
Heavy Formex	3/4	3/4	1	1
Heavy Alkanex	1/2	1/2	3/4	3/4
Heavy ML (Phelps Dodge)	3/4(?)	3/4	--	1
Heavy ML (FW-GE, 2 wires)	OK-1/8 Failed.050	OK-1/8	OK-1/8 Failed.050	OK-1/8
Heavy ML (FW-GE under cure)	---	3/4	---	1
Heavy ML (Sch'dy-GE, under cure)	---	1/2	---	1
Heavy ML (GE-2 bakes)	---	1/2	---	3/4
Heavy ML (GE-3 bakes)	---	OK-1/8	---	OK-1/8
.005 aluminum phosphate filled asbestos	1/4	1/2	1/4(1/2?)	1/2
.009 aluminum phosphate filled asbestos	(?)	1/4(?)	1/2	1/2
ML + .005 Al. phosp. felted asbestos	---	---	---	1/4
Teflon	---	1/4(1/2?)	---	1/2
Film Coated Nylon		3/4		1
Fused Fiber Coated Nylon	---	1	---	1
PVC - RC 220	---	$>$ 1 3/4	---	$>$ 1 3/4
PVC + Nylon - RC22N1	---	$>$ 1 3/4	---	$>$ 1 3/4

TEST SPECIMEN

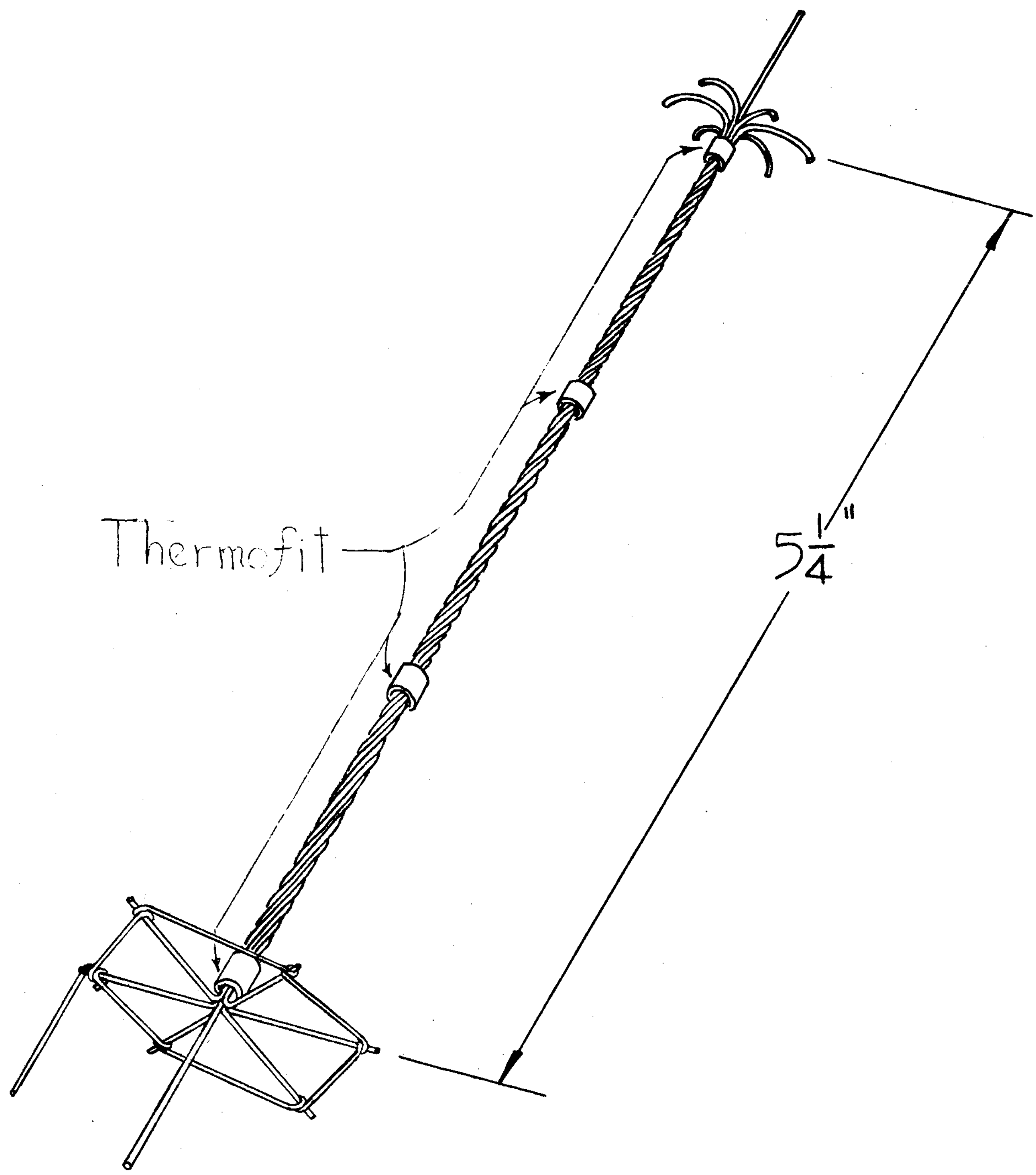


FIG. 1

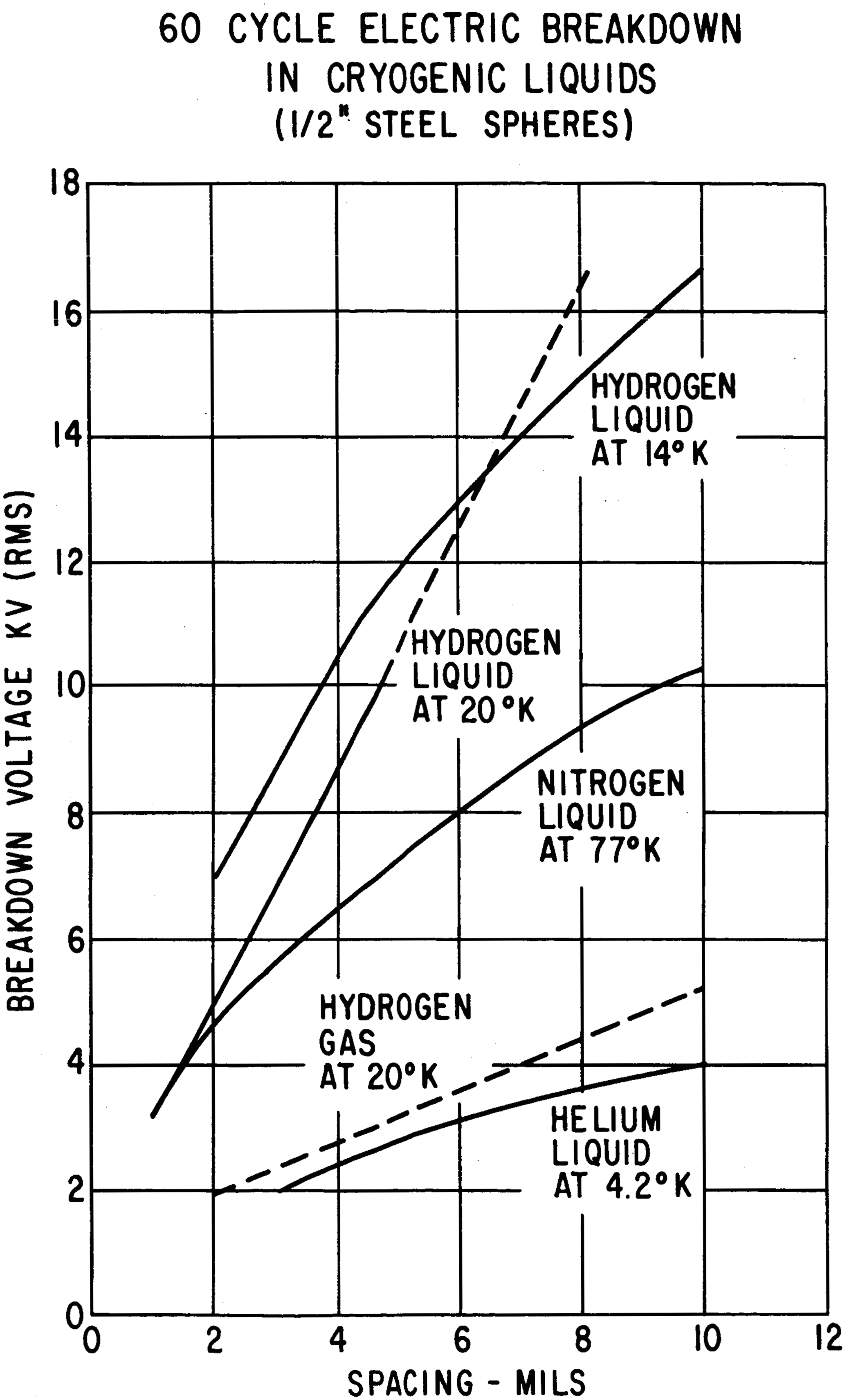
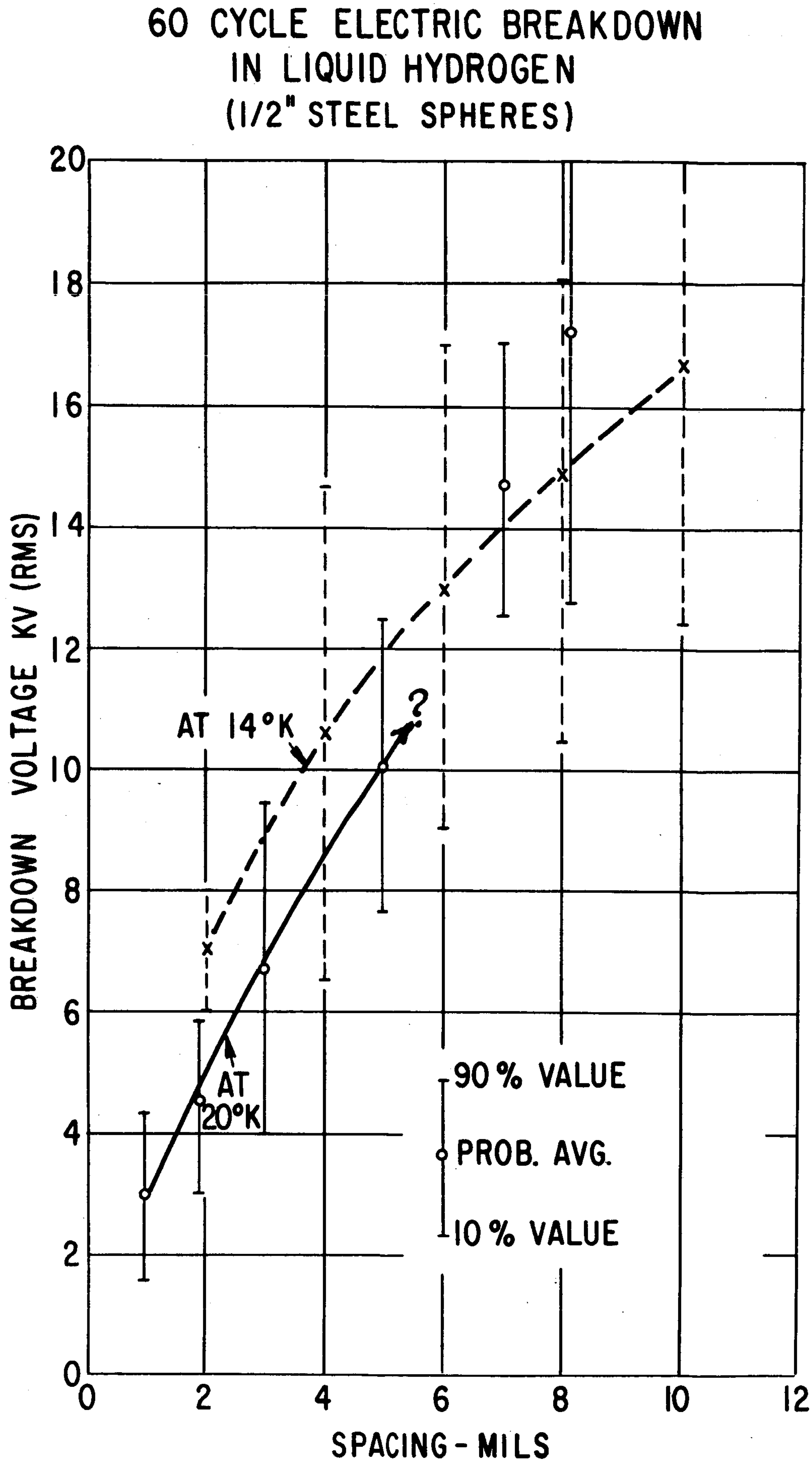
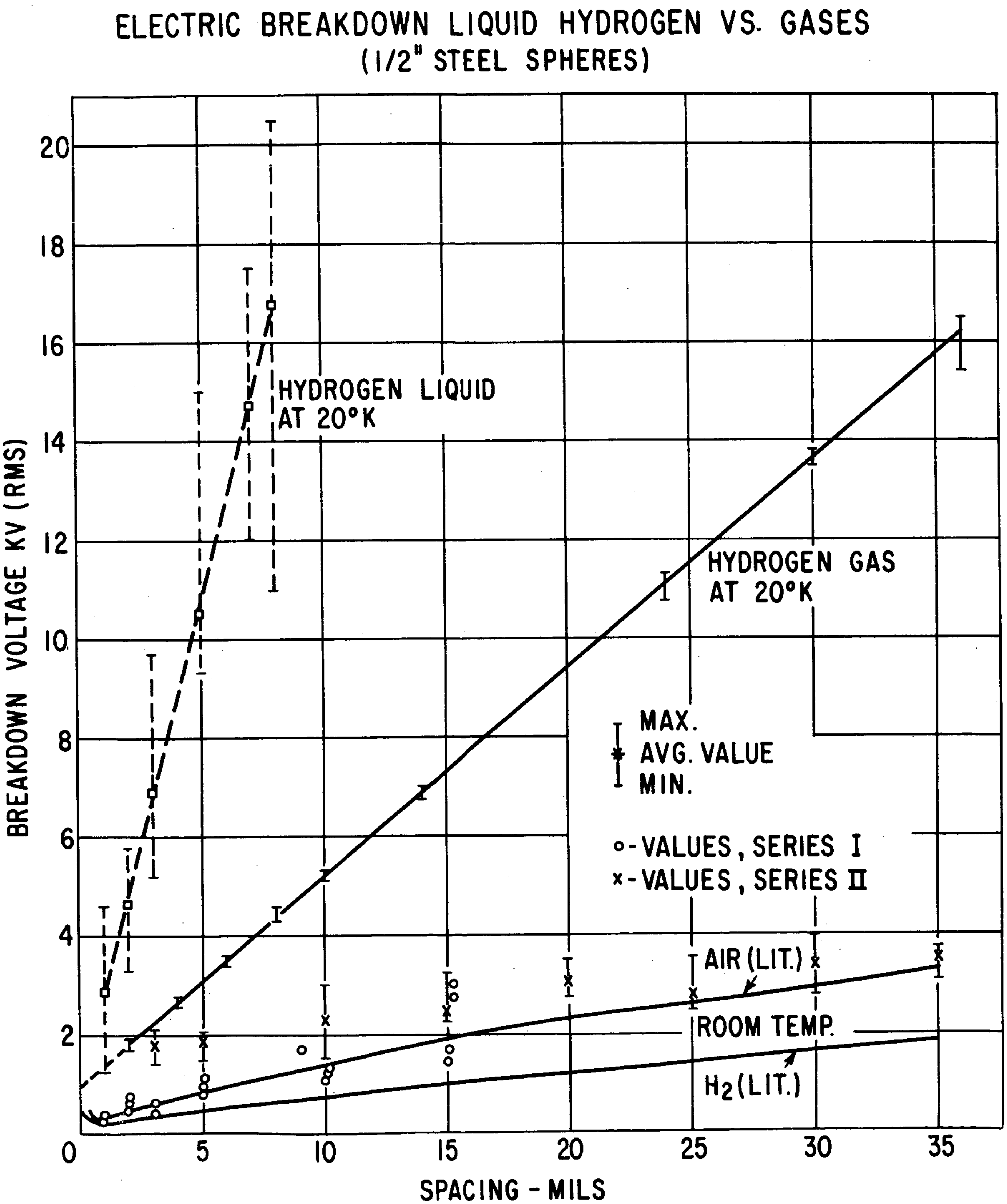

60 CYCLE ELECTRIC BREAKDOWN
IN CRYOGENIC LIQUIDS
(1/2" STEEL SPHERES)
BREAKDOWN VOLTAGE KV (RMS)
SPACING - MILS
HYDROGEN
LIQUID
AT 14° K
HYDROGEN
LIQUID
AT 20° K
NITROGEN
LIQUID
AT 77° K
HYDROGEN
GAS
AT 20° K
HELIUM
LIQUID
AT 4.2° K
0
2
4
6
8
10
12
14
16
18
0
2
4
6
8
10
12

FIGURE 2



60 CYCLE ELECTRIC BREAKDOWN
IN LIQUID HYDROGEN
(1/2" STEEL SPHERES)
BREAKDOWN VOLTAGE KV (RMS)
SPACING - MILS
AT 14°K
AT 20°K
?
90 % VALUE
PROB. AVG.
10 % VALUE
0
2
4
6
8
10
12
14
16
18
20

FIGURE 3



ELECTRIC BREAKDOWN LIQUID HYDROGEN VS. GASES
(1/2" STEEL SPHERES)
BREAKDOWN VOLTAGE KV (RMS)
SPACING - MILS
HYDROGEN LIQUID
AT 20°K
HYDROGEN GAS
AT 20°K
MAX.
AVG. VALUE
MIN.
o - VALUES, SERIES I
x - VALUES, SERIES II
AIR (LIT.)
ROOM TEMP.
H_2 (LIT.)
0
5
10
15
20
25
30
35
2
4
6
8
10
12
14
16
18
20

FIGURE 4

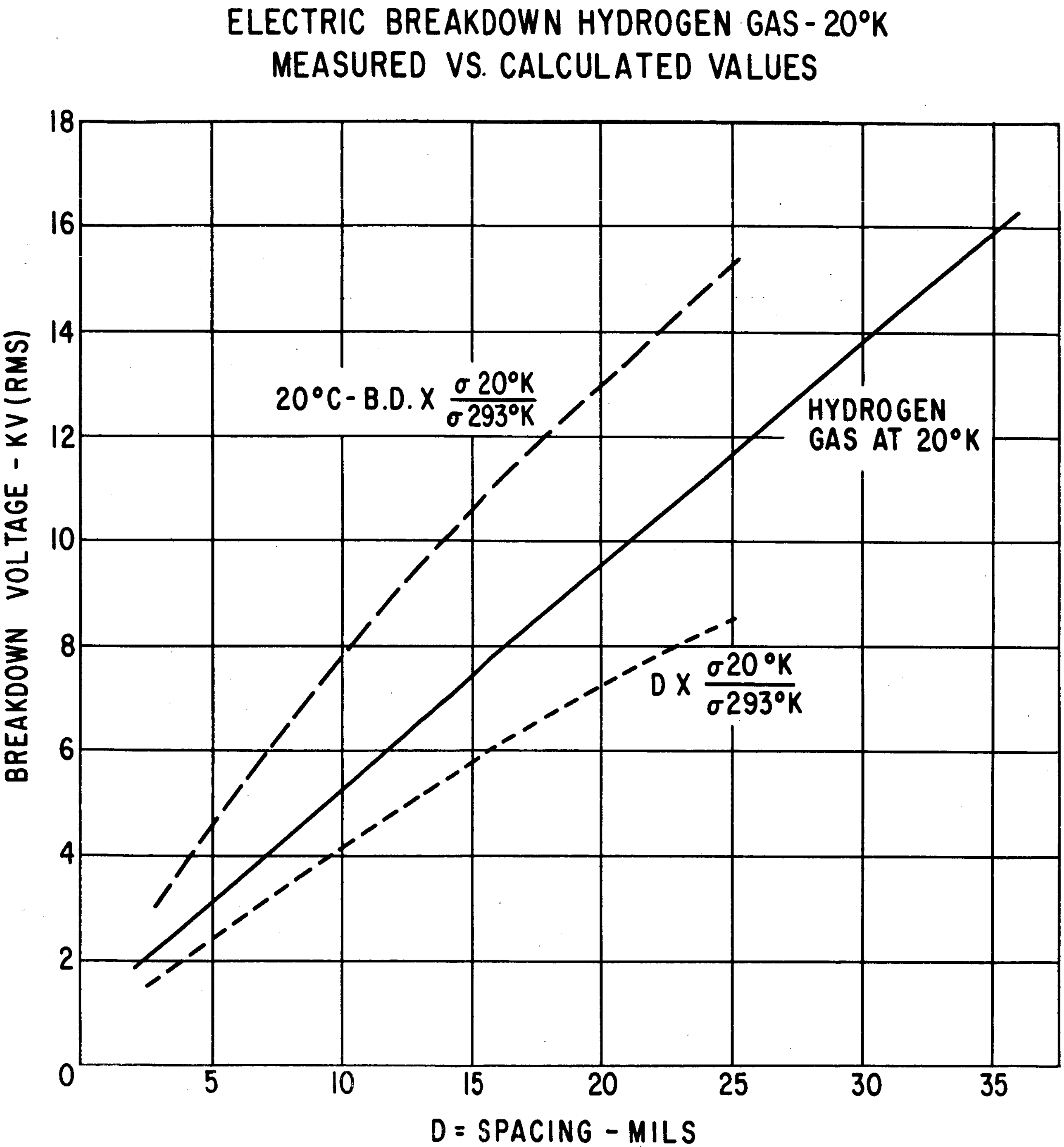
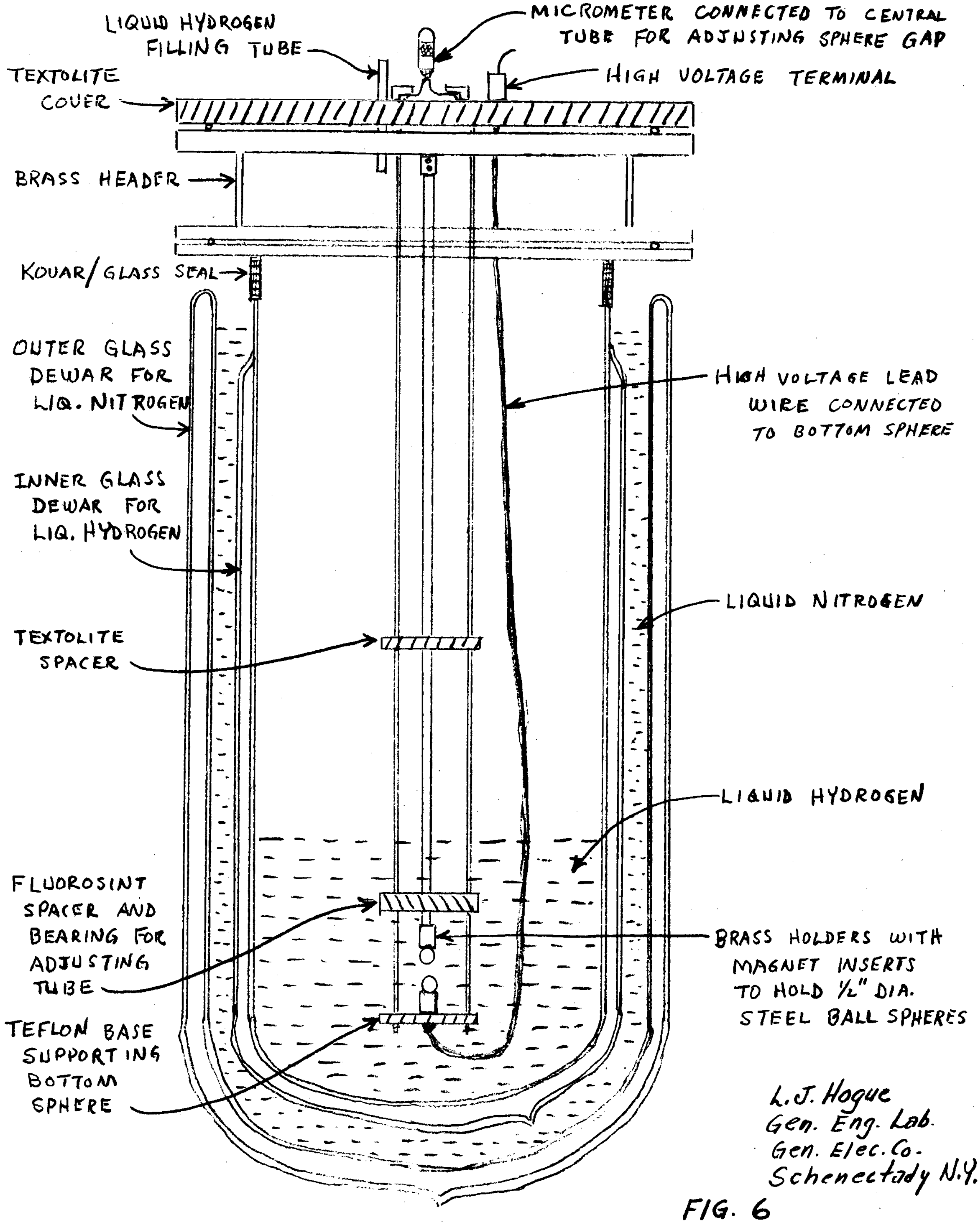

ELECTRIC BREAKDOWN HYDROGEN GAS - 20°K
MEASURED VS. CALCULATED VALUES
BREAKDOWN VOLTAGE - KV (RMS)
D = SPACING - MILS
20°C - B.D. X $\frac{\sigma\ 20°K}{\sigma\ 293°K}$
HYDROGEN GAS AT 20°K
D X $\frac{\sigma\ 20°K}{\sigma\ 293°K}$
0
2
4
6
8
10
12
14
16
18
5
10
15
20
25
30
35

FIGURE 5

SPHERE GAP BREAKDOWN DEVICE FOR TESTING LIQUID HYDROGEN



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Gen. Elec. Co.
Schenectady N.Y.

FIG. 6

BREAKDOWN DEVICE FOR TESTING TWISTED PAIRS OF WIRES IN LIQUID HYDROGEN

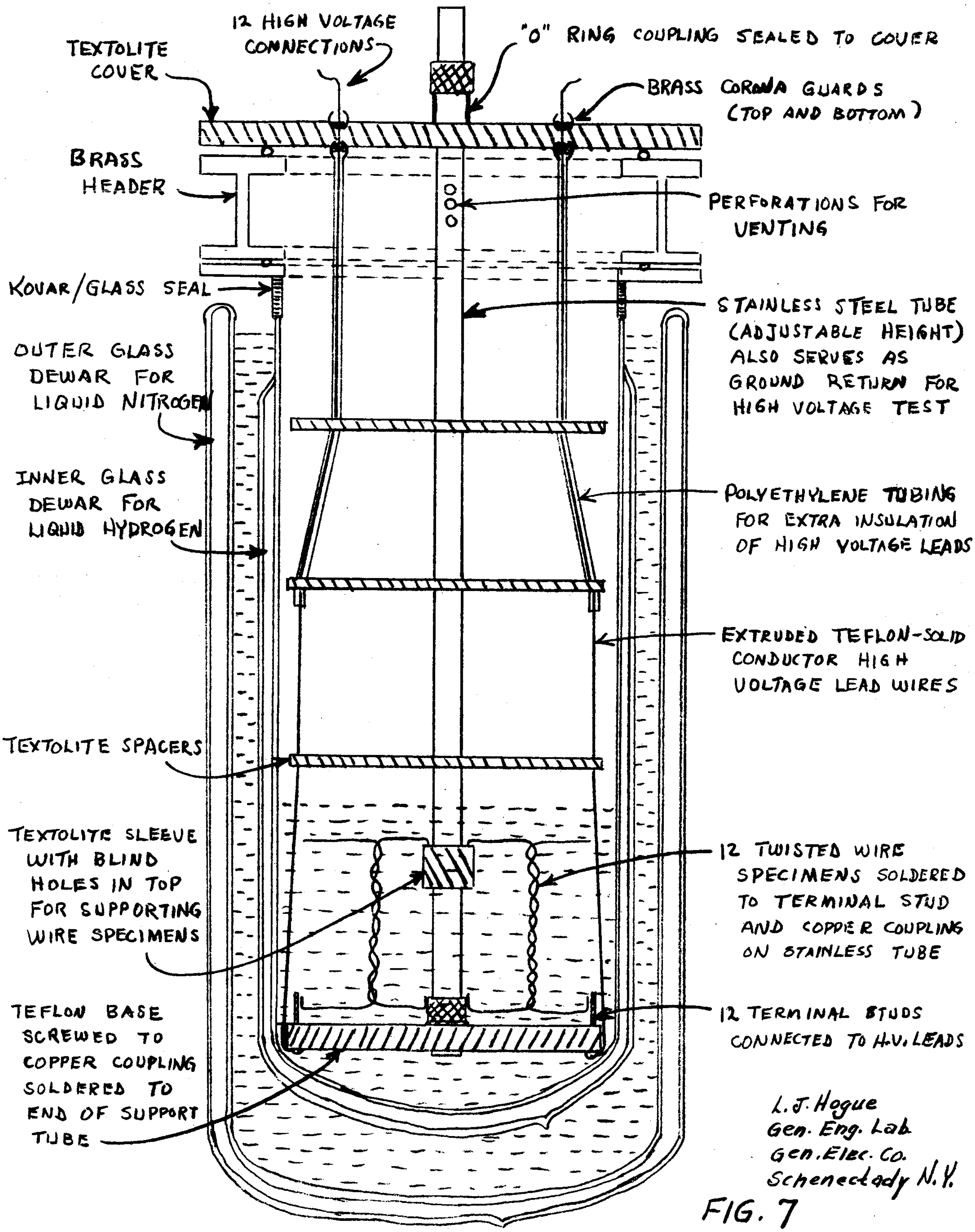

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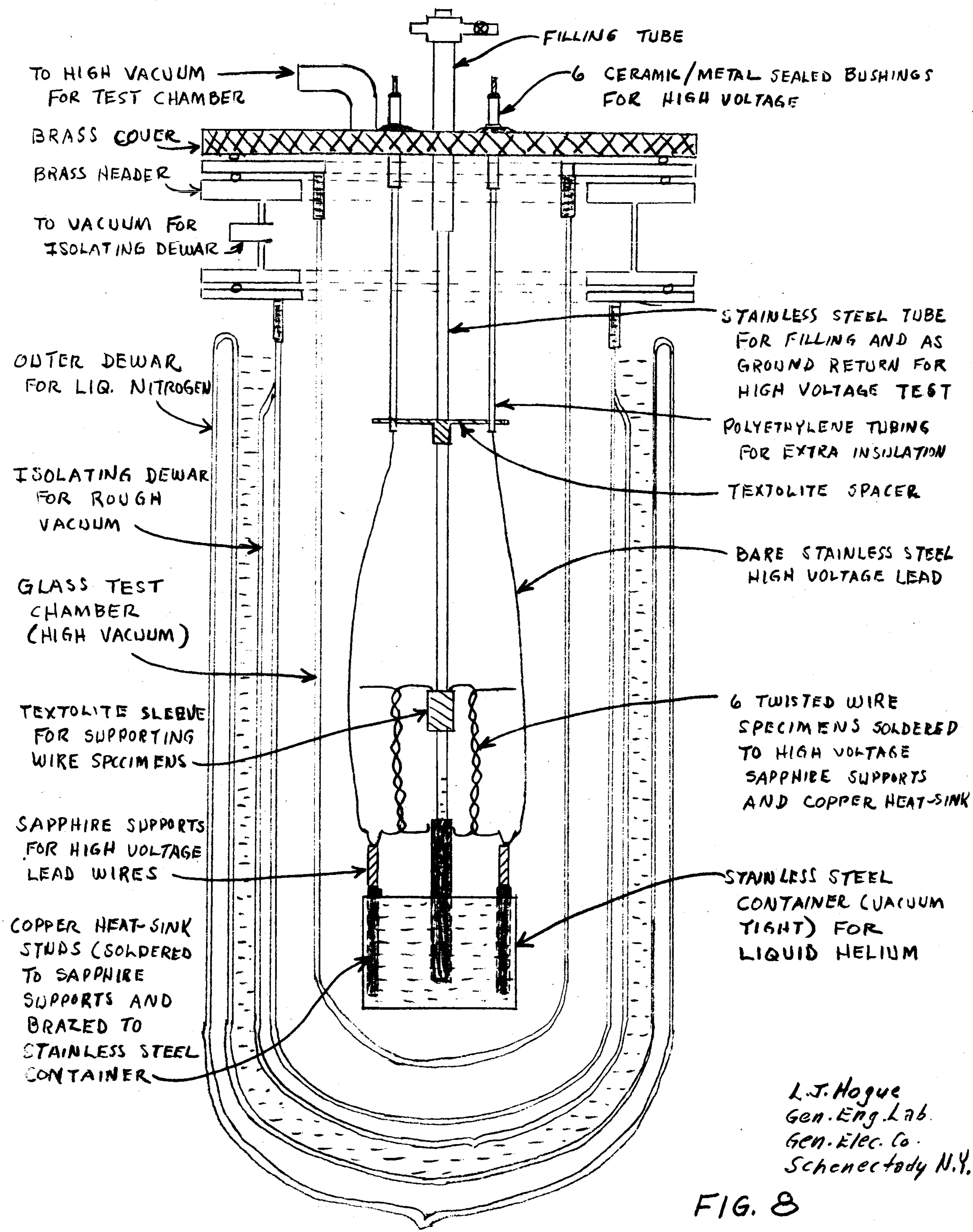
FIG. 7

BREAKDOWN DEVICE FOR TESTING TWISTED PAIRS OF WIRES IN VACUUM AT CRYOGENIC TEMPERATURES



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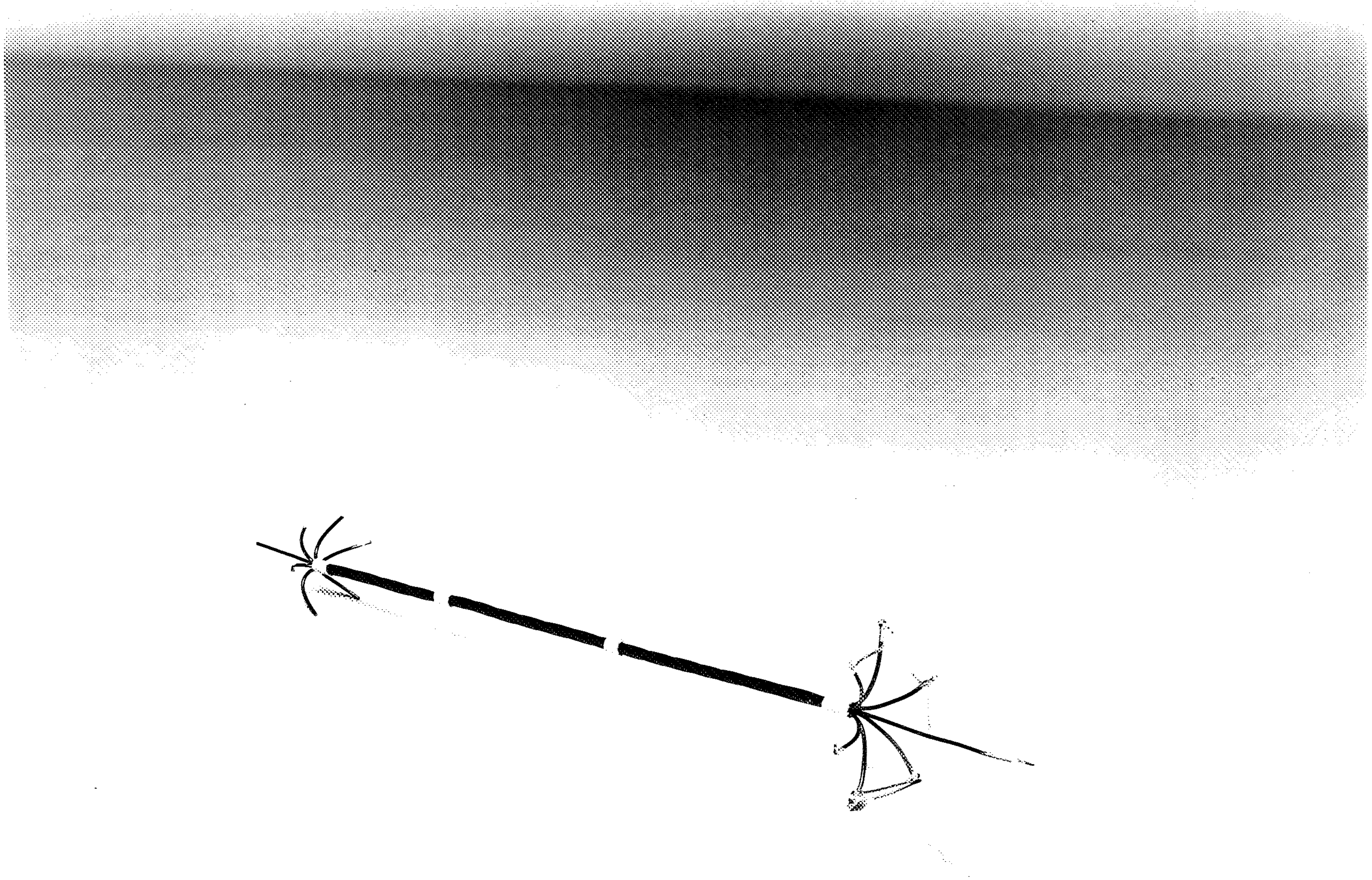
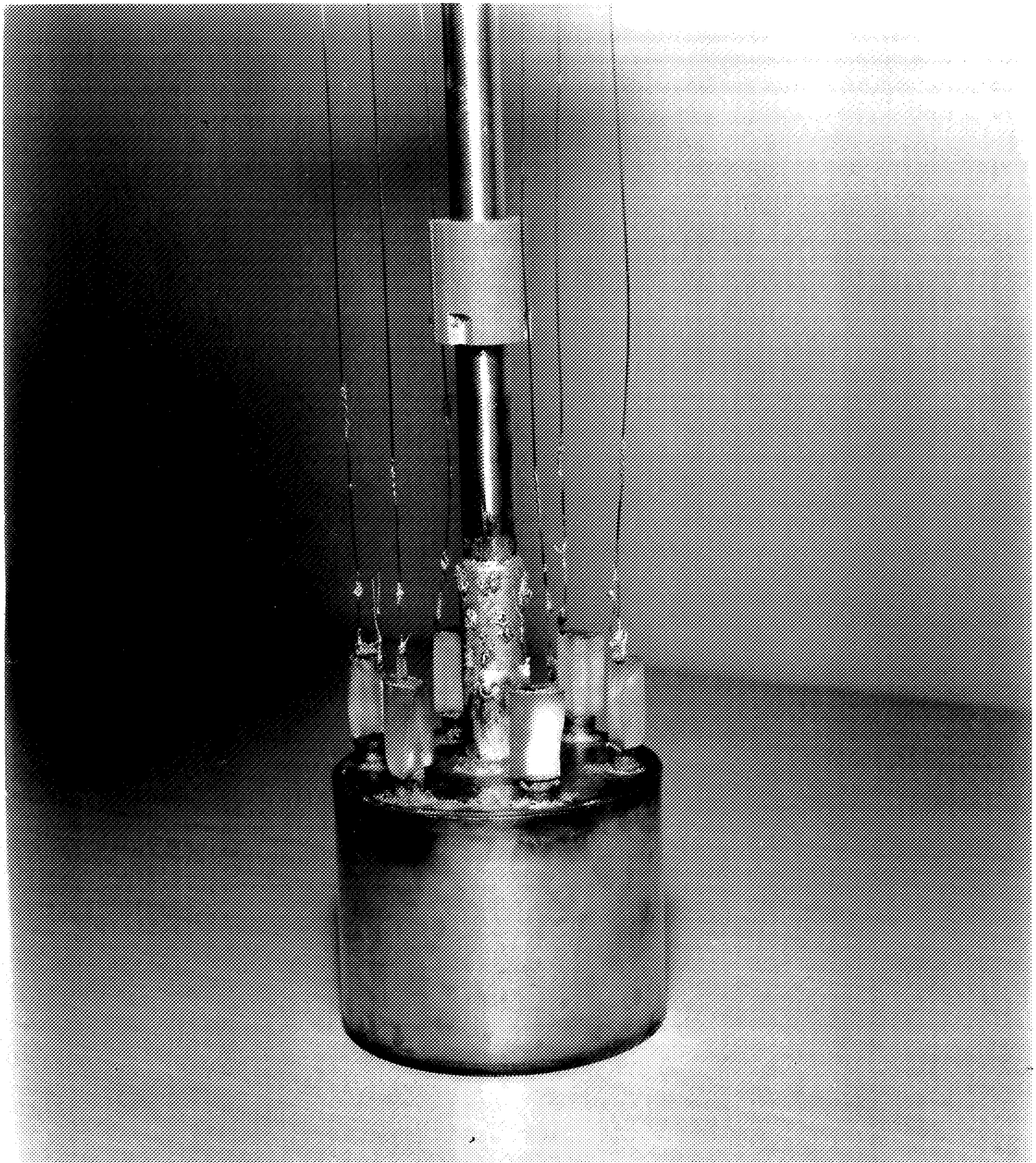
Schenectady N.Y.

FIG. 8

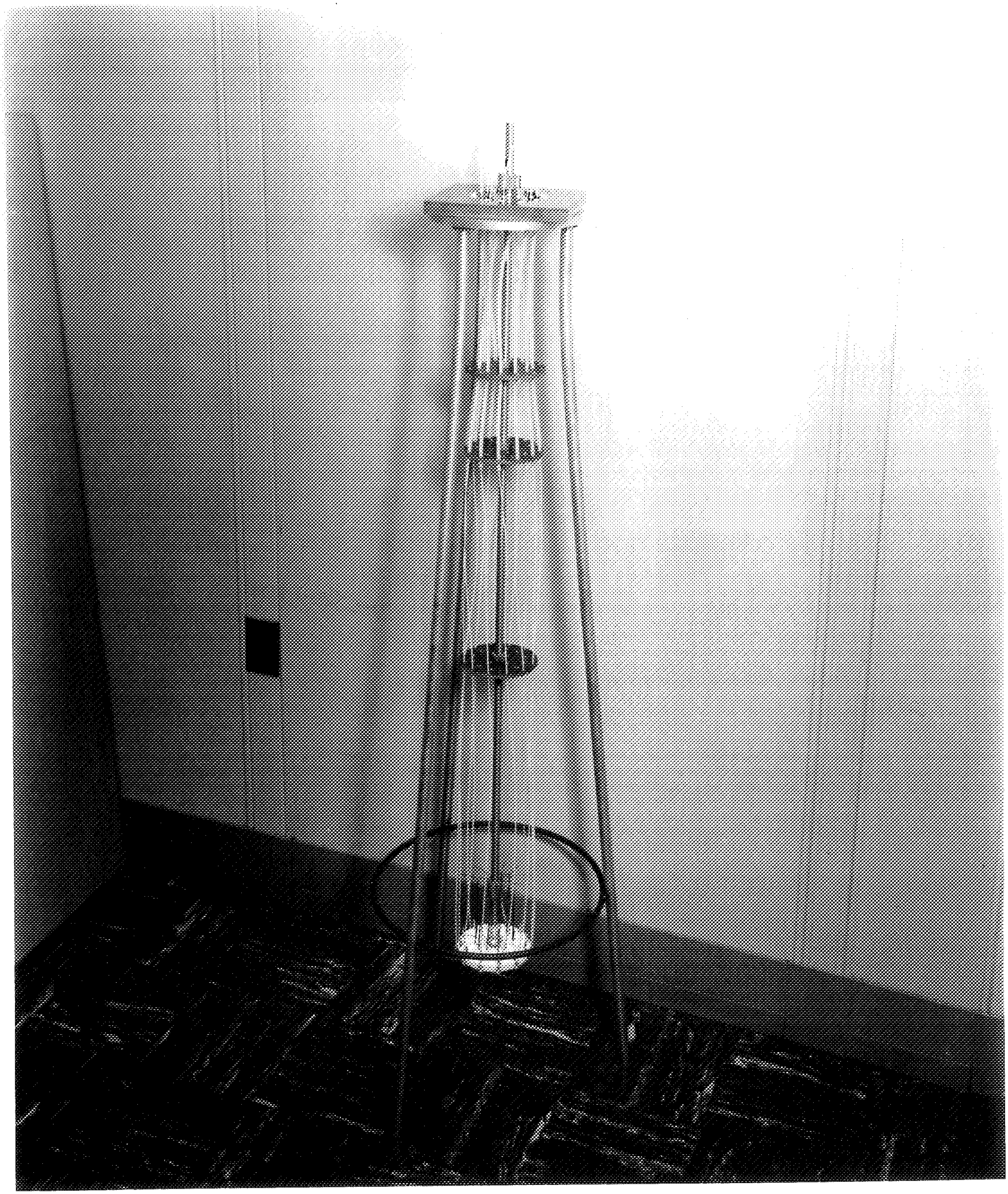


1180 612 DIELECTRIC MEASUREMENTS SPECIMEN. PHOTO #1. E369.4 E341.4 7-9-62

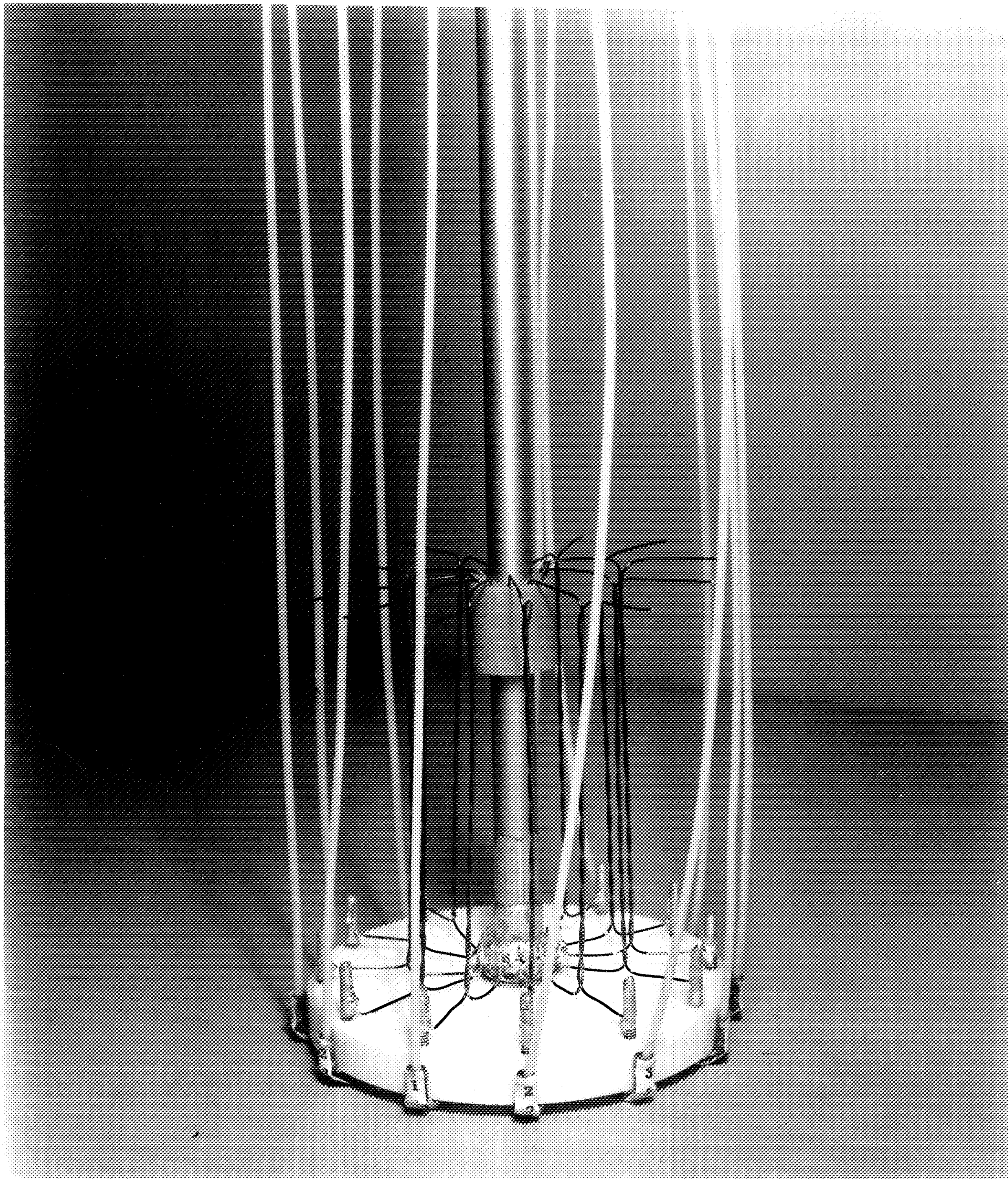
1180 611 OVER ALL VIEW OF VACUUM TEST DEVICE FOR TESTING TWISTED PAIRS OF WIRES. PHOTO #2.
E369.4 E341.4 7-9-62



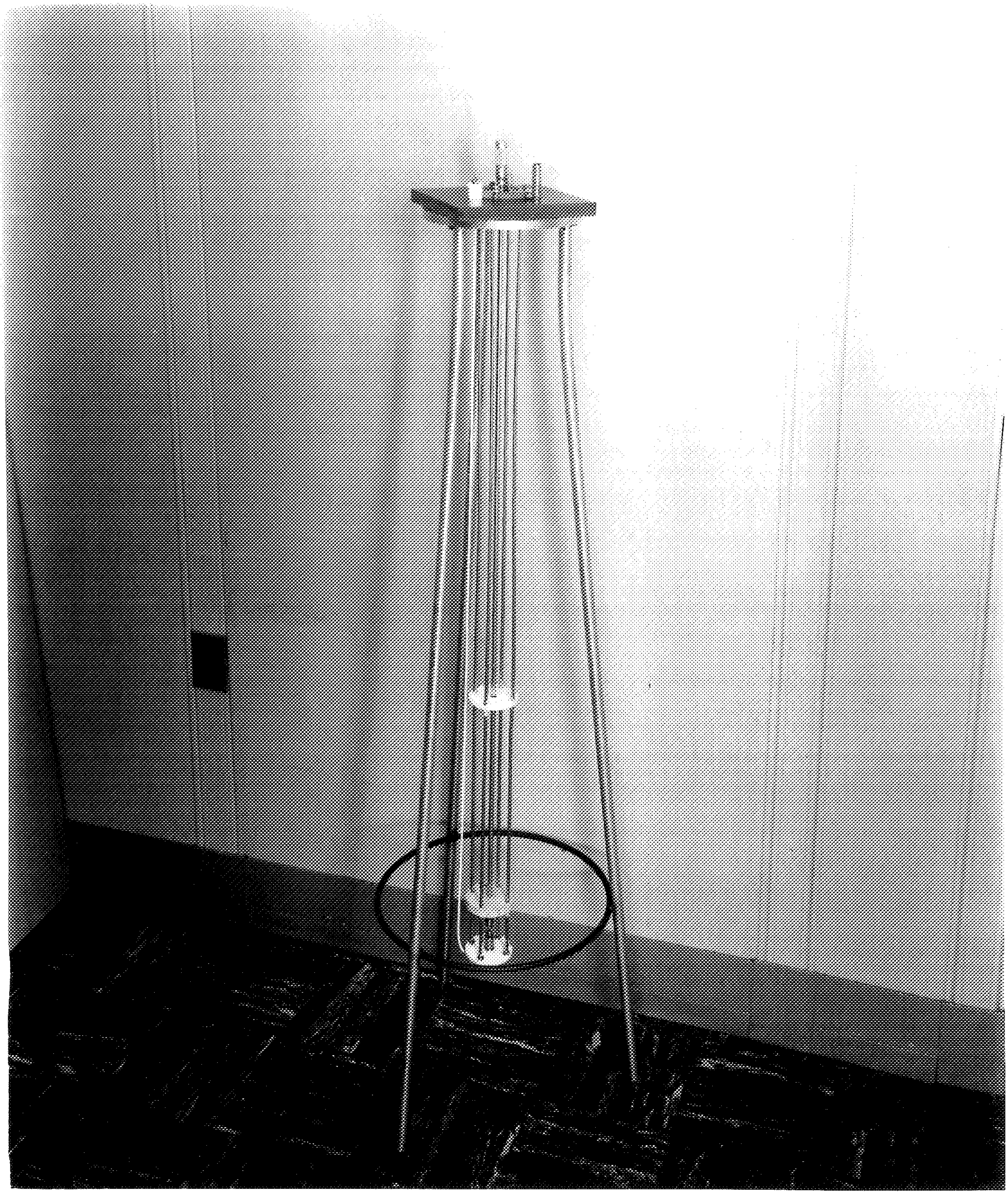
1180 614 SPECIMEN END OF VACUUM BREAKDOWN DEVICE SHOWING SAPPHIRE SLUGS SOLDERED TO COPPER HEAT-SINK RODS BRAZED INTO LIQUID HELIUM CONTAINER. (NO SPECIMENS IN PHOTO)
PHOTO #2-A. E369.4 7-9-62



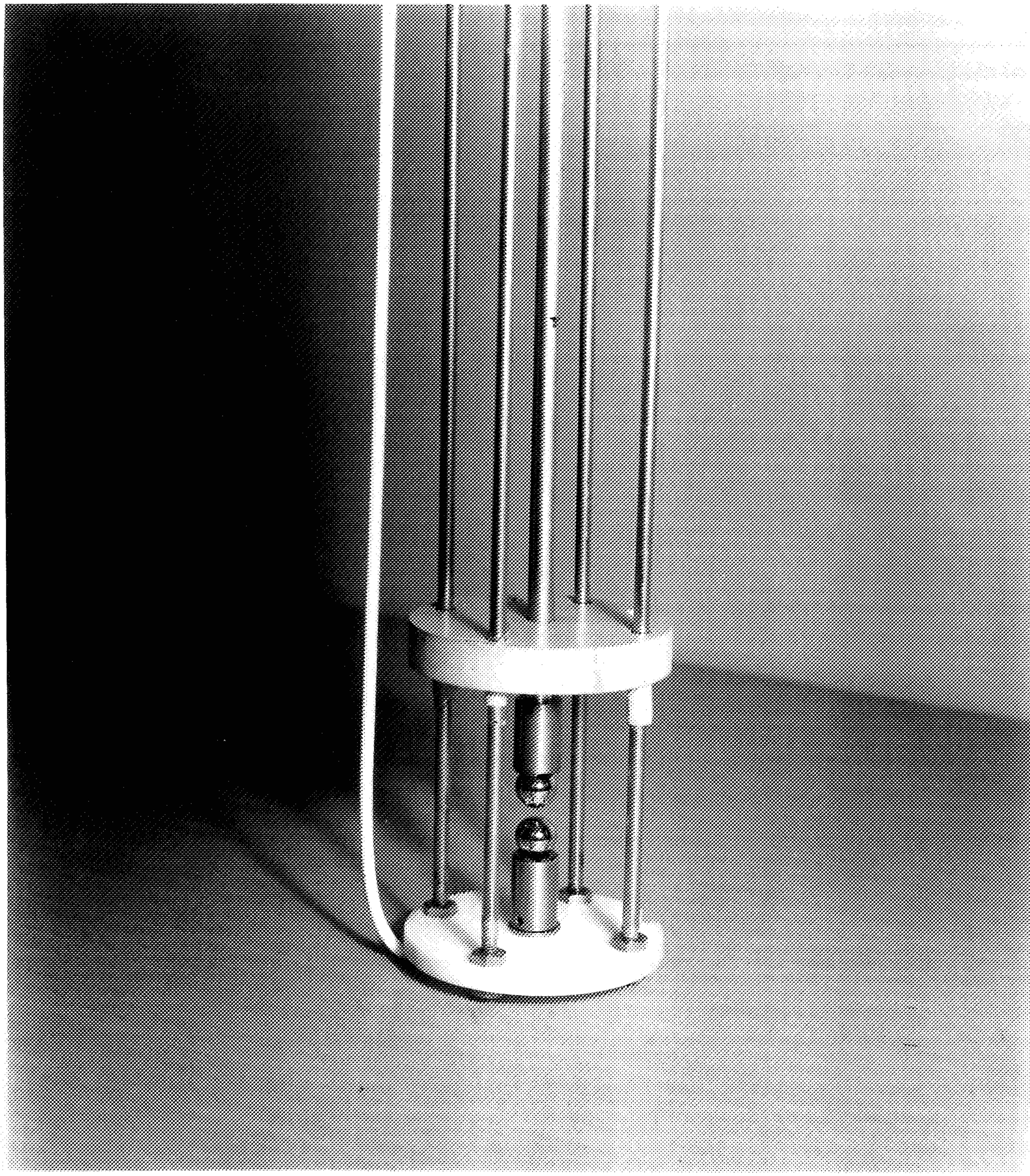
1180 610 OVER ALL VIEW OF DIELECTRIC BREAKDOWN DEVICE FOR TESTING TWISTED PAIRS OF WIRES UNDER LIQUID HYDROGEN. PHOTO #3. E369.4 E341.4 7-9-62



1180 615 CLOSE-UP OF TWISTED WIRE BREAKDOWN DEVICE FOR TESTING UNDER LIQUID HYDROGEN. NOTE SPECIMENS SUPPORTED BY TEXTOLITE SLEEVE AND SOLDERED TO TERMINALS AND CENTRAL CONNECTOR. PHOTO #3-A. E369.4 E341.4 7-9-62



1180 609 OVER ALL VIEW OF SPHERE GAP BREAKDOWN DEVICE FOR LIQUID HYDROGEN. PHOTO #4.
E369.4 E341.4 7-9-62



1180 613 CLOSE-UP OF SPHERE GAP TEST DEVICE FOR BREAKDOWN OF LIQUID HYDROGEN BETWEEN 1/2" DIA. STEEL BALLS. PHOTO #4-A. E369.4 7-9-62

421D441
GENERAL ELECTRIC
UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING
APPLIED PRACTICES 137A 900
SURFACES
TOLERANCES ON MACHINED DIMENSIONS
TITLE INSULATION BREAK-DOWN TEST DEVICE
FIRST MADE FOR
1 1/4 QUICK CONNECTOR
1 1/4 O.D. x 1/16 WALL BRASS NIPPLE
3/4 O.D. x 1/16 WALL x 6 1/2 LG. BRASS TUBE.
1 3/8 O.D. STREET ELBOW (90°)
1" SQ. BRASS
BRAZE
TO PUMP
50
6 1/8 REF.
44 1/2 REF.
LIQUID NITROGEN
LIQUID HYDROGEN
SAPPHIRE
CERAMIC SOLDER
SPLIT GUIDES 2 REQ'D, TAPE IN POSITION ON TUBE
5/8 O.D. x .010 WALL x 43 7/8 LG. TYPE 347 CRE. STL. TUBE
1/8 DIA, 4 HOLES EQ. SP.
3/16 DIA. COPPER
3 3/4 DIA.
801 SERIES TERMINAL #801B0666-19 CERAMASEAL INC.
GLASS
VACUUM 10^-4
HIGH VACUUM 10^-6
INNER DEWAR
OUTER DEWAR
PLEXIGLAS PROTECTIVE SHIELD
1/2 THICK x 9" O.D. BRASS
SPLIT RING 3/8 THICK BRASS
1/4-20 UNC-2B, 6 HOLES EQ. SP. ON 8" B.C.
9/32 DIA, 6 HOLES EQ. SP. ON 7 1/4 B.C.
1/8 SAWCUT
ADAPTER W-1207 "STREAMLINE"
VEECO L 62 S VALVE
3/4 O.D. x 1 1/4 LG. BRASS
A 432 "HOKE" VALVE
6 TERMINALS ON 2 3/4 DIA.
45° TYPICAL
9/32 DIA, 6 HOLES EQ. SP. ON 8" B.C.
1/16 DIA., 6 HOLES EQ. SP. ON 3 1/2 DIA.
TEXTOLITE SPLIT GUIDE
1/16 SAWCUT
6 RODS EQ. SP. ON 3" DIA.
3/4 O.D. x 1/16 WALL x 5" LG. COPPER TUBE.
SECTION A-A
1/32 COPPER
SECTION B-B
3/32 CRE. STL.
1/32 CRE. STL.
WELD
VIEW AT "C" (TOP & BOTTOM)
DESCRIPTION OF GROUPS
REVISIONS
PRINTS TO
MADE BY 11 MAY 62
ISSUED 11 MAY 62
APPROVALS
GEL SCH'DY
SKETCH
FF-612-P (9-60) REV. 1 PRINTED IN U.S.A.